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Laser probing of the kinetics and dynamics of III - V semiconductor growth

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Stephen R. Leone

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Work is carried out on the dynamics of Ga, In, and As scattering, sticking, and desorption from silicon single crystals using laser induced fluorescence probing of the Ga and In atoms and As dimer gas phase species. Desorption kinetics are used to probe the InAs and GaAs heterostructures on silicon and the islanding behavior that occurs for the mixed systems. It is observed that islands form readily when In or Ga are grown on a prelayer of As on Si(100). State-resolved detection of As_2 species is demonstrated by laser-induced fluorescence probing for the first time. Laser multiphoton ionization detection of the III-V semiconductor species is also demonstrated. A technique is being developed to measure surface migration rates of epitaxial species by using a two laser, desorption and detection scheme. These results are relevant to the epitaxial growth of GaAs and InAs on silicon.

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Annual Report of Progress

February 1, 1990 - 31 January 1991

Accomplishments in the past year have been made in the detection of gas phase arsenic species by laser-based methods (both laser-induced fluorescence and multiphoton ionization). These include state-resolved probing of As_2, the kinetics of desorption of As_2 from Si(100), studies of the interface between Ga and As on Si(100), and in laser desorption measurements of surface migration rates. Each topic will be summarized briefly below. No inventions have resulted from this work. We considered the possibility of a patent on the As_2 detection schemes, but determined that there is too much information already in the open literature which preceded this work.

We have devised an accurate method to probe As_2 dimer species, which can be used to measure fluxes from molecular beam sources or to interrogate desorbing or scattering material in the epitaxial growth process [J. Vac. Sci. Technol. B 8, 416 (1990)]. By utilizing calibrations of intensity factors in a heated cell of As_2 vapor, we can also measure reliably the vibrational population distributions of $As_2(v)$. Qualitative information can also be obtained for the rotational distributions. The method uses laser induced fluorescence (LIF) detection of As_2 at 230-250 nm in the ultraviolet on the $A\ ^1\Sigma_u^+ - X\ ^1\Sigma_g^+$ band. The technique is sufficiently sensitive to detect a fraction of a monolayer of arsenic upon desorption from a substrate.

We have also demonstrated a laser multiphoton ionization (MPI) time-of-flight (TOF) mass spectrometer detection scheme to observe As, As_2, As_3, and As_4 simultaneously. A short wavelength ultraviolet laser is focused into the flux of desorbing arsenic species, causing ionization by 2 and 3 photon absorption processes.

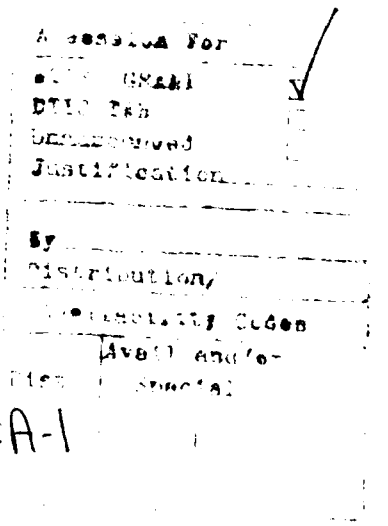
The ions are swept into a long flight tube by electric fields and the masses are detected by their arrival time. An important part of the design is a novel configuration which allows the TOF mass spectrometer to surround the substrate used for epitaxial growth. Unfortunately, the MPI process also produces fragments of neutrals and ions, causing the relative abundances of As, As_2, As_3, and As_4 to be altered. We are presently making a change to overcome this problem. The laser used will be a vacuum ultraviolet source at 118 nm by frequency tripling 355 nm (3rd harmonic of Nd:YAG), thus allowing gentle single photon ionization of the As_n species.

We have completed a study of the vibrational distribution of As_2 desorbing from Si(100). The vibrational temperature is 860 ± 100 K, while the surface temperature is 1140 K; this suggests a dynamical effect in the desorption process. An example would be the necessary utilization of vibrational energy to overcome the barrier to desorption of the As_2. We have also measured the desorption kinetics of As_2 from Si(100). The desorption kinetics are best fit by a second order process, however the measured activation energy and pre-exponential factors are unusually low, E = 1.7 ± 0.3 eV and $\nu = 10^{8\pm2}$ ML^{-1} s^{-1} (1 ML = 6.8×10^{14} atoms/cm^2). We are in the process of making more measurements to confirm these results. A simple bond energy picture suggests that a single As - Si bond is ~1.3 eV, if the As atoms each make 2 bonds to Si and one bond to another As atom.

We have completed a very thorough study of the GaAs interface, grown with a prelayer of As on Si(100) and with varying coverages of Ga on top of the As prelayer [J. Vac. Sci. Technol. B 8, 1102 (1990)]. The results show evidence for a true

compound interaction between the Ga and As species, but also show that there is a strong tendency for island formation in the early stages of the heteroepitaxy. The island formation creates large numbers of microcrystallites, which are reported in the device fabrication studies.

We have made an initial investigation of the use of a two laser technique to study surface migration rates. This type of study will be very important, for example, in migration enhanced epitaxial growth. One laser is used to desorb atoms from the surface, indium for example from Si(100). A second laser probes the concentration of desorbed atoms. After a delay time, the process is repeated to determine the amount of In that has migrated into the interaction zone of the first laser. The method has been shown to work, and current efforts are underway to obtain quantitative results for migration rates and to probe the mobilities of one species in the presence of the other.



Cumulative List of Publications

AFOSR-87-0119, AFOSR-90-0116

1 December 1987 - 31 January 1991

K. L. Carleton and S. R. Leone, "Laser probing of gallium atom interactions with silicon (100) surfaces," J. Vac. Sci. Technol. B 5, 1141 (1987).

K. L. Carleton, B. Bourguignon, and S. R. Leone, "Desorption of a two-state system: Laser probing of gallium atom spin-orbit states from silicon (100)," Surf. Sci. 199, 447 (1988).

B. Bourguignon and S. R. Leone, "Surface structure and growth mechanism of Ga on Si(100)," in Symposium on Atomic and Surface Physics '88 (Inst. de Recherche Fondamentale, 1988) p. 228.

K. L. Carleton, B. Bourguignon, R. V. Smilgys, and S. R. Leone, "Laser probing of the dynamics of Ga interactions with Si(100)," Mat. Res. Symp. Proc. Vol. 116, 45 (1988).

B. Bourguignon, K. L. Carleton, and S. R. Leone, "Surface structures and growth mechanism of Ga on Si(100) determined by LEED and Auger electron spectroscopy," Surf. Sci. 204, 455 (1988).

B. Bourguignon, R. V. Smilgys, and S. R. Leone, "AES and LEED studies correlating desorption energies with surface structures and coverages for Ga on Si(100)," Surf. Sci. 204, 473 (1988).

D. J. Oostra, R. V. Smilgys, and S. R. Leone, "Interaction of In atom spin orbit states with Si(100) surfaces," Mat. Res. Soc. Proc. 131, 239 (1989).

D. J. Oostra, R. V. Smilgys, and S. R. Leone, "Initial stages of heteroepitaxial growth of InAs on Si(100)," Appl. Phys. Lett. 55, 1333 (1989).

D. J. Oostra, R. V. Smilgys, and S. R. Leone, "Spin-orbit state specific laser probing of the desorption kinetics and islanding behavior of In on Si(100)," Surf. Sci. 226, 226 (1990).

R. V. Smilgys, D. J. Oostra, and S. R. Leone, "State-resolved laser probing of As_2 in a molecular beam epitaxy reactor," J. Vac. Sci. Technol. B 8, 416 (1990).

R. V. Smilgys, D. J. Oostra, and S. R. Leone, "A study of the GaAs - Si(100) interface using laser probing of thermal desorption kinetics," J. Vac. Sci. Technol. B 8, 1102 (1990).

Interactions, Seminars, Conferences

S. R. Leone

"Laser probing of III-V semiconductor growth on Si(100)," SPIE Symposium, Los Angeles, California, January, 1990.

"Laser probing of III-V semiconductor growth," University of Wisconsin, Madison, Wisconsin, March, 1990.

"Laser probing of the kinetics of semiconductor growth," University of Wisconsin, Milwaukee, Wisconsin, March, 1990.

"Laser probing of the kinetics and dynamics of semiconductor growth," IBM, Yorktown Heights, New York, September, 1990.

"Laser probing of the kinetics and dynamics of semiconductor growth," University of California, Berkeley, California, October, 1990.

"Laser probing of the kinetics and dynamics of semiconductor growth," University of California, Stanford, California, October 1990.

"Laser probing of the initial stages of GaAs growth on Si(100)," University of California, Irvine, California, October 1990.

R. V. Smilgys

American Vacuum Society Student Prize (1990)

American Vacuum Society, annual meeting, Toronto, Canada, presentation on "As_2 desorption dynamics"

Personnel

Stephen R. Leone - Principal Investigator

Russell V. Smilgys - Ph.D. received December 1990

Brenda J. Korte - Doctoral Student

Paul G. Strupp - Postdoctoral Researcher